

Process Specification for the Heat Treatment of Steel Alloys

Engineering Directorate

Structural Engineering Division



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REVISIONS		
VERSION	CHANGES	DATE
Baseline	Original version	5/96
A	Expanded sec. 3.0, furnace chart info., tensile requirements	5/27/98
B	Changed Training Requirements, Updated to SAE AMS-H-6875A	7/21/99
C	Modified Training Requirements, Labeling Tensile Bars & Stock	2/24/00
D	Included Information on Postweld Stress Relief, Reduced Labeling Tensile Bars & Stock Requirements	8/24/00
E	Changed sec. 6.0 on aging requirements for A286. Updated document due to reorganization from EM2 to ES4.	6/06/02

F	Reviewed for accuracy and updated author.	10/04/06
G	Clarified the Usage Statement	8/10/09
H	Verify current condition of raw stock material; added statement on tool and die steels; added Table 1 and Table 2; subdivided PROCESS VERIFICATION section; added ASTM E18 under REFERENCES section; replaced JSC 8500 with JPR 8500.4 under REFERENCES section; updated and added definitions to section 10.0; other grammatical changes.	10/2011

1.0 SCOPE

This process specification establishes the engineering requirements for the heat treatment of steel and stainless steel alloys.

2.0 APPLICABILITY

This specification shall be applicable whenever the heat treatment of steel or stainless steel alloys is invoked per section 3.0, "Usage". Heat treatment of steel and stainless steel alloys may be performed on raw stock material (includes, but not limited to, plate, bar, forgings, and extrusions) or on parts produced from raw material.

3.0 USAGE

The material to be heat treated shall be listed on the drawing, in the heat treat condition in which the material is to be procured; the procurement specification shall be listed alongside the material to be heat treated. Availability of product forms and tempers may be obtained from a manufacturing production controller or from an ES4 materials engineer.

This process specification shall be called out on the engineering drawing by using an appropriate drawing note. The specific heat treat process or combination of processes shall be noted along with the final temper. For example:

For Class A (Carbon and Low Alloy Steels):

QUENCH AND TEMPER TO 160-180 KSI PER NASA/JSC PRC-2001.

For Class B (Martensitic Corrosion Resistant Steels (CRES)):

QUENCH AND TEMPER AT 450°F PER NASA/JSC PRC-2001.

For Class C (Austenitic CRES):

ANNEAL PER NASA/JSC PRC-2001.

For Class D (Precipitation Hardening CRES and Maraging Steels):

AGE HARDEN TO CONDITION H1025 PER NASA/JSC PRC-2001.

3.1 PROCESS SEQUENCE

Unless otherwise specified on the engineering drawing, all parts shall be heat treated before final machining to remove scale and decarburization, as well as to avoid dimensional changes. Scale and decarburization, typically produced at temperatures above 1200°F, are normally detrimental to the finished part and cannot be removed by mechanical or chemical finishing techniques. After heat treating, a minimum of 0.020" will be removed from all scaled or decarburized rough machined surfaces during final machining.

In some cases, it may be necessary to heat treat after final machining. It is recommended to restrict heat treat processes to those which will be performed at low temperatures or for a short time in such cases. Heat tint which ranges in color from straw to light blue may be formed during these low temperature or short time heat treatments. It may be required to remove heat tint for cosmetic purposes. An appropriate finishing procedure to remove the heat tint shall be called out on the engineering drawing, if heat treating will result in a heat tinted surface that will not be removed by final machining. For example:

HEAT TREAT AFTER FINAL MACHINING. REMOVE HEAT TINT BY ELECTROPOLISHING PER NASA/JSC PRC-5009.

Class A and Class B steels often require a stress relieving heat treatment after welding operations. Stress relieving after welding should be performed as soon as possible after the welding operation, typically within 2 hours as specified in section 3.2.4.4 of SAE AMS-H-6875. Post stress relieving on Class C and Class D steels may not be necessary for specific reasons. A qualified welding procedure for the specific application needs to be reviewed before making the stress relieving note. For example:

STRESS RELIEVE AT 1000°F FOR 2 HOURS IMMEDIATELY AFTER WELDING

4.0 REFERENCES

All documents listed are assumed to be the current revision unless a specific revision is listed.

SAE AMS-H-6875

Society of Automotive Engineers, Inc.,
Aerospace Material Specification, *Heat Treatment of Steel Raw Materials*

SAE AMS 2759	Heat Treatment of Steel Parts General Requirements
ASTM E18	American Society for Testing and Materials Specification, <i>Rockwell Hardness and Rockwell Superficial Hardness of Metallic Materials</i>
ASTM A370	American Society for Testing and Materials Specification, <i>Standard Test Methods and Definitions for Mechanical Testing of Steel Products</i>
MMPDS	Handbook, <i>Metallic Materials Properties Development and Standardization</i>
TI-2000-01	Training Instruction: Training for Heat Treat Personnel
SAE ARP 1962	Training and Approval of Heat-Treating Personnel

The following references were used in developing this process specification:

SOP-007.1	Preparation and Revision of Process Specifications
JPR 8500.4	Engineering Drawing System Requirements

5.0 MATERIALS REQUIREMENTS

Current heat treat condition shall be verified (i.e: MTRs) before performing any subsequent heat treatment on raw stock material. Subsequent heat treatment shall be performed per AMS-H-6875.

Material requirements for parts shall be as specified in AMS 2759.

6.0 PROCESS REQUIREMENTS

6.0.1 Raw Stock Steel and Stainless Steel Material

All heat treatment of raw steel and stainless steel alloys shall comply with the requirements specified in section 3 of SAE AMS-H-6875 and the corresponding drawing requirements.

Specific heat treating times and temperatures are provided in various tables in SAE AMS-H-6875. Table 1 provides a list of these heat treating tables.

Table 1: List of Tables with Heat Treating Times and Temperatures Per SAE AMS-H-6875

Table	Name
1A	Heat-Treatment Procedure for Class A (Carbon and Low Alloy) Steel
1B	Heat-Treatment Procedure for Class B (Martensitic Corrosion-Resistant) Steel
1C	Annealing Procedure for Class C (Austenitic Corrosion-Resistant) Steel
1D	Heat-Treatment Procedure for Class D (Precipitation-Hardening and Maraging) Steel
2A	Heating and Holding Time for Annealing, Normalizing, Austenitizing, and Stress Relieving Class A Steel and Class B Steel
2B	Holding Time for Class C (Corrosion-Resistant) Steel
3	Required Tempering Conditions

An exception to Table 1D must be noted when age hardening A286. The age hardening time and temperature provided by Table 1D yields the minimum tensile strength that can be attained for A286, without cold working the material. The tensile strength of A286 can be increased by the amount of cold work input into the material. The age hardening time and temperature for A286 material that has been cold worked is not listed in Table 1D. The corresponding material specification(s) shall be used to age harden A286 material that has been cold worked.

Tools and equipment shall be as specified in SAE AMS-H-6875. Safety precautions and warning notes shall be as specified in SAE AMS-H-6875.

6.0.2 Steel and Stainless Steel Alloy Parts

All heat treatment of steel and stainless steel alloy parts shall comply with the requirements specified in section 3 of AMS 2759 and the corresponding drawing requirements.

Specific heat treating times and temperatures are provided in various derivations of AMS 2759. Table 2 provides a list of these AMS 2759 derivations.

Table 2: List of AMS 2759 Derivations

Steel and Stainless Steel Heat Treat Procedures	AMS 2759 Derivations
Carbon and Low-Alloy Below 220 ksi UTS	AMS 2759/1
Low-Alloy 220 ksi UTS and Higher	AMS 2759/2
PH and Maraging	AMS 2759/3
Austenitic	AMS 2759/4
Martensitic	AMS 2759/5
Gas Nitriding	AMS 2759/6

Gas and Vacuum Carburizing	AMS 2759/7
Ion Nitriding	AMS 2759/8
Hydrogen Embrittlement Relief (Baking) of Steel Parts	AMS 2759/9
Automated Gaseous Nitriding Potential	AMS 2759/10
Stress Relief of Steel Parts	AMS 2759/11
Gaseous Nitrocarburizing, Automatically Controlled by Potentials	AMS 2759/12
*Heat Treatment of Parts in a Vacuum	AMS 2769

*Not an AMS 2759 specification.

Tools and equipment shall be as specified in AMS 2759. Safety precautions and warning notes shall be as specified in AMS 2759.

6.0.3 Tool and Die Steels

An ES4 materials engineer shall be consulted for process requirements and specific heat treating times and temperatures for heat treatment of tool and die steels.

7.0 PROCESS QUALIFICATION

Not required. However, work instructions shall be generated for implementing this process specification. The work instructions shall contain sufficient detail to ensure that the manufacturing process produces consistent, repeatable products that comply with this specification.

8.0 PROCESS VERIFICATION

8.0.1 Verification of Heat Treat Cycles

Verification of furnace temperatures shall be accomplished by recording the furnace temperatures on strip charts or other suitable hard copy recordings. Furnace charts for heat treatment shall be maintained with the hardware's work order router package (or equivalent documentation).

8.0.2 Heat Treat Verification by Hardness Test

Heat treat verification of steel and stainless steel is typically achieved by measuring hardness per ASTM E18.

8.0.2.1 Notations Related to Hardness Tests

Hardness tests will be performed on the raw stock material or the semi-finished part unless otherwise specified on the engineering drawing. Hardness impressions will be machined away during subsequent machining for most parts. When hardness impressions must be made on the finished part, a test location shall be chosen by the designer and the materials engineer that will not be detrimental to the function of the finished part. Notes must be included on the engineering drawing, such as:

HARDNESS TEST SHALL BE PERFORMED ON FINISHED PART IN SPECIFIED LOCATION

Hardness tests may be performed on sample parts instead of finished parts. Sample parts shall be sketched and/or described on the engineering drawing. They may have a simplified contour and may use nominal dimensioning. Sample parts shall be made from the same lot of raw stock material and shall be processed before heat treatment in an identical manner as the finished parts.

When the heat treating process includes quenching, the sample parts must be of similar cross section as the finished parts, or shall be parted from the same lot of raw stock material that will be used for finished parts post heat treatment. If finished parts have to be processed in more than one batch and sample parts are needed, each batch must have its own set of labeled sample parts.

When a hardness test is to be performed on a sample part, special instructions shall be included on the engineering drawing, such as:

HARDNESS TEST SHALL BE PERFORMED ON SAMPLE PART. SAMPLE PART SHALL CONSIST OF ONE 1" LENGTH OF THE SAME RAW STOCK MATERIAL USED FOR FINISHED PARTS.

OR

HARDNESS TEST SHALL BE PERFORMED ON 2" PROLONGATION OF RAW STOCK MATERIAL THAT IS PARTED AFTER HEAT TREATMENT.

8.0.2.2 Hardness Test Results

Hardness test results shall meet the values that appear on the procurement specifications or the drawing requirements.

8.0.3 Heat Treat Verification By Tensile Test

When tensile tests are required by the drawing for more critical parts, tensile tests shall be performed according to ASTM A370 by either the JSC Structures Test Laboratory, the Receiving Inspection and Test Facility (RITF), or an accredited mechanical testing laboratory.

8.0.3.1 Notations Related to Tensile Tests

Sample parts for tensile coupons shall be machined according to ASTM A370, using full-sized coupons whenever possible. Sample parts shall be machined from the same lot of raw stock material and processed before heat treatment in an identical manner as the finished parts. The number of coupons, grain direction (when applicable), and any special acceptance criteria (i.e: tensile strength, % elongation, etc) shall be noted on the engineering drawing when tensile testing is required. For example:

TENSILE TESTING IS REQUIRED AND SHALL BE PERFORMED ON SAMPLE PART(S). SAMPLE PARTS SHALL CONSIST OF THREE 6" LENGTHS OF THE SAME RAW STOCK MATERIAL LOT USED FOR FINISHED PARTS.

8.0.3.2 Labeling of Tensile Coupons

Tensile coupons shall be labeled individually. Label information shall always include material lot certification #. If the tensile bars or tensile coupons are made prior to heat treating, the tensile bars or tensile coupons shall be labeled using austenitic stainless tags and austenitic stainless wire. If the tensile bars or tensile coupons are made after heat treating, cotton string and paper tags may be used instead of stainless tags and wire. Paper tags shall include the material type, the material lot certification #, and the work order router number.

8.0.3.3 Tensile Test Results

Tensile test results for Class A, Class B, and Class C steels shall meet the yield strength and elongation drawing requirements per MMPDS. Tensile tests are not required to verify annealed condition of Class C steels.

8.0.4 Miscellaneous

Hardness testing and tensile testing are not required post weld stress relieving operations, except for rare exceptions.

9.0 TRAINING AND CERTIFICATION OF PERSONNEL

All heat treatment of steel and stainless steel alloys used for flight hardware shall be performed by qualified operators who have been certified according to the requirements in TI-2000-01, Training for Heat Treat Personnel. For vendors, a training program consistent with the recommended practices in SAE ARP 1962 shall be required.

10.0 DEFINITIONS

Material Lot	a single batch (bar, forging, extrusion, etc.) of material that is produced by the vendor and is documented by a certificate of compliance.
Annealing	heating to and holding at temperature, followed by slow cooling
Normalizing	an austenitizing heating cycle followed by cooling in air; applicable only to steels
Austenitizing (Solution Heat Treatment)	forming austenite (solid solution of one or more elements in face-centered cubic iron, solute is generally carbon) by heating a ferrous alloy into the transformation range or above the transformation range
Quenching	cooling from the austenitizing or solution heat treating temperature
Cryogenic Treatment	enhances the transformation of retained austenite, after quenching, to martensite
Tempering	reheating hardened steel; decreases hardness, increases ductility and toughness
Age Harden	aging which causes hardening constituents to strain and strengthen the lattice
Decarburization	loss of carbon from the surface of a carbon-containing alloy by reaction with other elements (usually oxygen) during heat treatment.
Heat Tint	a thin, tightly adhering oxide layer that forms when steels are heat treated at low temperatures, or for a short time, in air or in a mildly oxidizing atmosphere; the color ranges from straw to light blue.

Scale	a heavy, penetrating oxide layer that forms when steels are heat treated at higher temperatures, or at longer times, in air or other oxidizing atmospheres.
Stress Relieving	heating to a suitable temperature (50°F below the tempering temperature), holding long enough to reduce residual stresses, and then cooling slowly enough to minimize the development of residual stresses